An Assessment of Landsat 7/ETM+ Coverage of Coral Reefs Worldwide

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ABSTRACT

This paper presents the state of the Landsat 7 archive of high resolution, multi-spectral imagery of coral reef after nearly 10 months of operation.

INTRODUCTION

Our maturing awareness of our home planet reveals mounting evidence that human activity is gradually altering the landscape of our fragile ecosystem. To understand whether such changes are damaging or benign to nature's delicate balance, it is vital that we improve our methods of monitoring our biosphere because we are intimately connected to it, and it to us. Among the interconnected components of this biosphere are coral reef ecosystems, the study of which contributes valuable feedback regarding the health of our vast shallow coastal waters upon which we are so dependent. It is alarming that we are discovering many of these coral reefs in peril [1] despite their tremendous socio-economic value [2]. This demands an accounting of the extent of the possible damage, and further research into the cause and effect of this spreading degradation. It also demands that we closely monitor the coral reefs at risk for trends to determine how the long term implications of the deteriorating health of coral reefs will impact our own future well being.

The Landsat 7 remote sensing mission incorporates monitoring of barometers of the health of our planet. In support of the Executive Order for Coral Reef Protection [3], the Landsat 7 mission has been implementing since June 1999 a coordinated plan to periodically acquire satellite remote sensing imagery of coral reefs in its mission to survey the landmass extents of the entire planet [4]. Prior to Landsat 7, multi-spectral/high resolution imaging coverage of coral reefs was sparse at best, and non-existent for many regions. Although these acquisitions present an extra burden on a mission that was designed principally for land survey, the coral reef science objectives have justified the diversion of a portion of the mission resources toward periodic imaging in shallow coastal regions to fulfill the coral reef research and monitoring demands.

LANDSAT 7 LONG TERM ACQUISITION PLAN

The daily acquisition plan of Landsat 7 selects up to 250 scenes per day for acquisition. Since the candidate pool of scenes consists of an average of 600 or more scenes per day, the selection process is automated. (The complexity of manually planning the daily acquisitions would otherwise be bewildering because the mission must consider the dynamics of cloud avoidance among many other factors in the daily planning process.) As a solution to this, the Landsat 7 program developed a Long Term Acquisition Plan (LTAP) which derives the daily acquisition plan. The LTAP aims to acquire and periodically refresh an archive of sunlit, substantially cloud-free land and shallow coastal scenes to analyze variations in land cover in the context of global change [5]. The LTAP anticipates demand for imagery based on regional seasonality, history of acquisitions, and history of imaging success (clear acquisitions). The LTAP specifies the desired acquisition rates per season for each global scene. Thus, image acquisition is targeted for regions experiencing change. The daily acquisition plan is compiled each day into a spacecraft command load that will direct the acquisition of imagery in accordance with this plan; however, the daily acquisition plan must also avoid regions with high predicted cloud cover, conform to limited image processing budgets

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and storage capacities, and comply with spacecraft instrument constraints.

Of the roughly 14,000 distinct global scenes targeted by LTAP for routine acquisition, 878 of these have been identified as containing coral reefs. There are a total of 8742 reefs [6] covered within these 878 scenes. Many of these coral reef scenes reach a high rate of acquisition owing to their proximity to coastal land already planned for acquisition. As a result, 70% of the reefs have acquisition rates of twice per year or more, 65% have acquisition rate of 4 times per year, and 33% are acquired as often as possible (typically 5 or more times per year).

The LTAP has assigned a high priority to 111 of these scenes covering 604 reefs that are currently classified as at risk, under study, or planned for study in the near future. Of the 604 high priority reefs, 53.7% have acquisition rates of 12 or more times per year, 45.5% are targeted for acquisition quarterly, and only 0.8% will be acquired only twice per year.

There are 19 scenes containing coral reef exclusive of the 878 targeted for acquisition. Due to their isolation from any other scenes targeted by LTAP for acquisition, these scenes are not presently in the plan, but they may be considered for a targeted campaign following one full year of mission operations after July, 2000.

PERFORMANCE

It is one thing to formulate a plan, but the success of a plan is in its application. So how are we doing with it? To date, Landsat 7 has achieved a high rate of image acquisition of scenes containing coral reefs. The LTAP, along with the added benefits of Landsat 7's cloud avoidance strategy, has resulted in an average acquisition rate of nearly 4 images per scene during the first 10 months of operations, with an average cloud cover of 25.8%. To date, 3500 images containing coral reefs have been acquired and archived in the period between June 30, 1999 and April 21, 2000. This represents 99.8% coverage of all targeted coral reefs. (Only one of the 878 scenes has yet to be acquired.) 38.9% of all coral reef images are clear (10% or less cloud contamination) according to the Landsat 7 automated cloud cover assessment [7]. Of these 3500 images, there is at least one clear image covering 79% of the 877 distinct coral reef scenes acquired, and 44% have at least two clear images. 95% of all coral reef scenes have been imaged at least once with a cloud cover of 25% or less, and 75% have been imaged at least twice with less than 25% cloud cover. Considering the best (least cloudy) image of each coral reef scene, the average cloud cover of the resulting picture would contain only 6.7% cloud cover. However, there is evidence that cloud cover assessments over oceanic islands may be underestimated, which will require further investigation.

Table 1 lists the acquisition and cloud cover statistics for all targeted reefs along with itemized statistics by geographic region.

In remote sensing, acquisition success is quantified not only by the volume and geographic distribution of the acquired imagery, but more essentially, by the quality and temporal dispersion of the imagery. A significant measure of image quality is the absence of cloud contamination. Under the direction of the LTAP, it is evident that our acquisition strategy is a tremendous success using this measure. As a result, on-going coral reef research programs are now using Landsat 7 images for change detection analysis (Florida Keys), to assess hurricane impacts (Pacific Isl.), to improve spatial models of coral reef populations (Caribbean reefs), to stratify *in situ* surveys of local biodiversity (Indian Ocean and Red Sea reefs) and to estimate superficies of coral reef ecosystems in remote inaccessible areas (Pacific Isl.) [8].

Notable in the results shown in Table 1 are the elevated acquisition rates for reefs in regions contained in or contiguous with scenes having high acquisition priority. The mission policy to always acquire scenes of the United States tends to elevate the acquisition rates for bordering reefs, such as North Pacific (Hawaii), Baja Peninsula, and the Caribbean. Along with these increased acquisition rates comes a slightly inflated average cloud cover than would otherwise be achieved because the cloud avoidance strategy has less influence on the acquisition decisions of these scenes.

SUMMARY

The Landsat 7 program is exceedingly pleased with the mission performance to date, not only with the coverage of coral reefs, but with the coverage and quality of the imagery as a whole resulting from the LTAP and cloud avoidance strategies. The mission performance to date has exceeded the expectations predicted by pre-mission models [9], and the coverage and quality of coral reef scenes is no exception.

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Table 1 – Coral Reef Acquisition Statistics

Region	Average Acquisitions per scene	Average Cloud Cover	Best Cloud Cover [c]	% Clear Images [a]	1 or more clear images [b]	2 or more clear images [b]
	3.5	22.3 %	5.3 %	37.0 %	82 %	44 %
	3.7	28.2 %	5.8 %	39.6 %	78 %	47 %
	4.5	21.7 %	7.1 %	35.6 %	76 %	52 %
	3.8	33.4 %	9.2 %	26.7 %	73 %	26 %
	6.1	9.5 %	0.1 %	75.5 %	100 %	87 %
	2.7	27.2 %	5.8 %	39.6 %	83 %	37 %
	5.2	23.6 %	4.8 %	38.3 %	90 %	44 %
	3.3	5.1 %	0.1 %	87.0 %	100 %	89 %
	4.0	34.1 %	8.8 %	24.4 %	69 %	34 %
	2.9	21.8 %	5.5 %	45.7 %	87 %	45 %
	3.2	32.4 %	11.5 %	27.6 %	62 %	24 %
	3.4	21.8 %	5.8 %	40.0 %	84 %	44 %
	7.2	24.5 %	4.0 %	41.3 %	86 %	69 %
	4.9	44.7 %	15.9 %	17.7 %	33 %	27 %
	3.9	***25.8 %***	***6.7 %***	***38.9 %***	***79 %***	***44 %***

[a] Clear image is 10% or less cloudy

[b] Portion of the region in which at least 1 (or 2) clear image(s) have been acquired per scene

[c] *Best Cloud Cover* represents avg. cloud cover of the region if the clearest image available is considered for each scene.

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